Environmental Stress and Human Migration in a Low-lying Developing Nation: A Comparison of Co-evolving Natural and Human Landscapes in the Physically and Culturally Diverse Context of Bangladesh

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LONG-TERM GOALS

The relationship between environmental conditions and human migration is multidimensional and complex, and few studies have addressed exactly how this two-way relationship operates and under what conditions environmental concerns affect migration decisions. We observe that the complexity of issues facing low-lying regions such as Bangladesh demand a significant advance in knowledgebase on migration and human-environment interactions. From this view we have identified the overarching goals of our project to be: (1) identify social and environmental factors most important in maintaining stability, from households to communities, or for motivating decisions to migrate; (2) determine how these factors differ within and across diverse social and physical landscapes; and (3) assess how these variables are likely to interact under a variety of scenarios for social and environmental change.

OBJECTIVES

Our research starts from the observation that both the people and the landscape of Bangladesh have a long history of resilience. We focus our study in southwest Bangladesh because this region has (a) a diverse physical environment, (b) variation in the ways that communities provide for themselves and interact with one another, and (c) is vulnerable to a broad range of natural and anthropogenic environmental stresses. Within this varied human and physical landscape, we seek to identify patterns of resilience and adaptation to environmental challenges and to understand the role of migration, both as a strategy to enhance resilience and as a response to failures of resilience.

1. Identify the types and characteristics of adaptive community models that comprise the socioeconomic landscape of southwest Bangladesh. How do groups self-organize to be successful in the face of changing environment, and social and economic pressures? What are the strategies and sources of livelihood? How do these vary with socioeconomic differences?

2. Identify the factors (physical, engineered, political, economic, social) that are most important in defining adaptive community models, including their successes, failures, and resilience. Which factors exhibit positive or negative influences on the various community strategies? Which factors are

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trending toward increasing or declining importance, and over what spatial and temporal scales are they felt? Are factors endogenous or exogenous, and under whose control?

3. Quantify dynamics of the natural and human-modified physical landscapes relative to sea-level change. What is the mass balance of sedimentation relative to rising sea level and subsidence? What are principal sediment sources and transport pathways sustaining vertical landscape aggradation? How has poldering of the inhabited islands impacted landscape dynamics?

4. Assess the source and dynamics of water supplies in the region. Where and why are there locally fresh groundwaters within a regionally saline aquifer? What role do anthropogenic modifications of the floodplain play in recharge? How are tidal channels interconnected with the groundwater system?

5. Determine how these physical and human systems are coupled and co-evolving. How are communities adapted to the dispersed and variable sources of potable water? How does the relationship between people and their environment vary with different livelihood strategies? How have community resilience and household vulnerability changed in response to engineered structures, shifting land use patterns, natural hazards, and long-term environmental change?

APPROACH

Project Model – In Year 1 we designed an overarching project framework that we refer to as an Integrated Social, Environmental, and Engineering (ISEE) model (Fig. 1), derived from the SES model developed by Elinor Ostrom and others through years of collaborative research on complex environmental and social systems. Our ISEE model integrates social, environmental, and engineering data in the study of human-environment coupling. The research can take place within any number of contexts (shown in purple), each of which defines a unique perspective on the coupled human-environmental system. The study context acts as a prism through which we identify and measure a number of factors (shown in blue) that describe aspects of the human-environmental interactions relevant to the study context. Interactions among these factors are analyzed to identify patterns of action by which the populace makes its livelihood. We analyze these patterns to identify dynamic equilibria (shown in green) through which communities are able to provide for themselves under ordinary conditions, and which are also sufficiently flexible to adapt to changing stresses in the physical and human environments. A major underlying hypothesis of this conceptual framework is that a community whose livelihoods comprise multiple dynamic equilibria will be more resilient, because it can adapt to the collapse of any single equilibrium by shifting activity to another.

Study Area – We chose to set our research in the context of the poldered (embanked) landscapes of southwest Bangladesh (Fig. 2), where environmental stresses from groundwater salinity, waterlogging, storm surges, and land-use change are among the most severe in the nation. Social factors such as poverty, politics, cultural diversity, and shifting livelihoods associated with the shrimping industry are also relevant, interacting strongly with these environmental factors (Fig. 3). Within this region, we have focused our Year 1 efforts on a particular poldered island that was devastated when its embankments were breached in five locations during a May 2009 cyclone (Fig. 4). Most of these breaches were not repaired until spring 2011, with one major breach still open today. During much of the intervening two years, the landscape remained intertidal, displacing 1000s of families and precluding agriculture or shrimp production, two of the principal livelihoods in the area.

Field Research – Our field efforts to date include a 4-week, interdisciplinary field campaign to the study area in May 2012, involving four PIs (Goodbred, Ackerly, Gilligan, Ayers), three graduate students, and numerous local partners from Khulna University (K. Roy, D. Datta), Dhaka University (S. Imtiaz), and Jahangirnagar University (M. Anam). A follow-up field effort is currently underway to retrieve late wet-season physical data. Working within the ISEE framework, the May 2012 field effort was aimed at testing our approaches and populating the ISEE model with quantitative and qualitative data from the study area. These field efforts have focused on identifying and measuring the important variables operating within the study area (blue factors in ISEE) and defining the numerous dynamic community structures that have emerged within this particular set of variables (green equilibria in ISEE).

Methods – The social-science group, headed by Brooke Ackerly, gathered community-level qualitative data during May 2012 field campaign. This team used a mixed-method approach that included Participatory Rapid Appraisal (PRA), Key Informant Interviews (KII), and Focus Group Discussions (FGD), aimed at gathering data on livelihoods, mobility, common pool resources, and evidence of community stability and instability. These data are being analyzed to identify key physical, engineered, social, economic, and political factors that contribute to community stability and instability. These initial field results are currently being incorporated into final drafts of the ethnosurvey in preparation for a late 2012 pilot study (Donato and Carrico).

The physical-science group, headed by Steve Goodbred, led a team from Vanderbilt, Dhaka, and Khulna universities to the field in May 2012, followed by a reconnaissance data collection in October 2012 led by post-doctoral fellow, Carol Wilson. The physical-science team used a fast-static GPS and theodolite campaign to measure absolute elevations of the landscape and engineered-structures within the study area (Steckler). Sedimentation rates were measured by shallow coring and an array of surface sediment traps. In conjunction, data loggers for water elevation, conductivity, temperature, and suspended sediment (via OBS) were deployed along three tidal channels (Goodbred). Surface and groundwater resources were evaluated by chemical analyses (ICP-OES, IC, TOC) to identify mixing trends between tidal channels, drinking water ponds, brine shrimp ponds, and tubewells in May and October 2012 (Ayers). Tidal-groundwater interactions were further investigated through a one-dimensional groundwater flow model interacting with two tidal river channels (Hornberger).

The integrative team, headed by Jonathan Gilligan, is using a GIS framework to assemble and manage the database on a dedicated server (Camp and Abkowitz). Meta-analysis of the dataset is just initiating now as the field data is refined and incorporated into the GIS framework. Also being coupled with the GIS framework are initial results from remote-sensing analysis of tasked and archival satellite images. These are being analyzed using multi-scale, multi-temporal spectra-mixture modeling, Combined Empirical Orthogonal Function Analysis, and temporal mixture modeling (Small). These efforts will provide the foundation for initial development of the agent-based modeling effort in the coming year.

WORK COMPLETED

Following our stated project schedule for the period June 2011 to September 2012, we have achieved the following: (1) set near-term project goals, listed in Objectives section, (2) developed an integrated transdisciplinary ISEE research framework, (3) identified our focus study area, (4) conducted intensive field research, (5) established permanent GPS and hydrodynamic monitoring sites, and (6) begun remote-sensing and GIS-based activities. These achievements to date match our goals for Phase Ø (6/2011-9/2011) and Phase 1 (10/2011-9/2012) stated in the research proposal. For Phase Ø these

include: project design, team organization, literature review, method integratation, site selection, and project plan. For Phase 1, these include: conducting community surveys, gather existing physical and remote-sensing data, install GPS devices, conduct physical-environment field surveys, gather existing and new data into GIS database schema, and at the end of this phase, deliver the finalized ethnosurvey format (nearly complete). Details of the most important work are given in the Approach section.

RESULTS

Our research is still in its early stages, but we believe that our conceptual framework will be able to contribute to identifying the most important vulnerabilities and the most important opportunities to build and enhance resilience in the face of environmental stress from natural and human causes. Awareness of the connections between a changing physical environment and changes in social, political, and economic conditions has the potential to inform decision-making, both at the policy-making level of choosing which measures to pursue and in effectively implementing those measures.

Integrative Results – From our first year of field research and literature review, we propose that varability in the strategies and resilience and vulnerability of communities in dynamic coastal environments are best understood as *multiple dynamic equilibria*: communities in environmentally vulnerable regions are shaped by multiple, overlapping interactions between the physical environment in which people live and the social, economic, and political environments in which they interact. By extension we posit that translating policy goals into effective action requires understanding these interactions at multiple levels.

Our research suggests that political dynamics, perhaps more than careful planning, affect development and post-disaster aid decisions. This is true of some disaster assistance following Cyclone Aila and of some larger-scale, longer-term aid efforts. Principal among these are the unanticipated consequences of widespread poldering in the region. Preliminary research suggests that potentially effective technologies are implemented without understanding how people will use them, rendering efforts toward increased resilience ineffective, or possibly even detrimental by demotivating local adaptive strategies.

Our initial results also reveal that a better understanding of the dynamics between human and environmental systems can potentially find productive middle ground in politically sensitive controversies. In particular the growth of shrimp aquaculture in the region introduces a complex array of costs and benefits whose import cannot be assessed without a broader analysis of the social, economic, and political dynamics and power relations. While we do not yet fully understand the dynamics of shrimp aquaculture in a poldered environment, we have seen a range of impacts and varying dynamic equilibria among those communities who are involved.

Physical Results – Our first year of research on the physical environment has documented a profound contrast between natural and human-modified landscapes, the latter having been ‘protected’ by embankments since the 1960s to increase arable land for paddy cultivation and for flood protection. Our field work has demonstrated that land-surface elevations lie 1.0-1.5 m lower than that of adjacent river-bank terraces outside of the embankments and the largely pristine Sundarbans mangrove forest. These observations indicate that the poldered landscapes have experienced 2-3 cm/yr of relative sea-level rise over the past 50 years, comparable to the most severe IPCC climate-change scenarios.

A second key finding is that severe impacts from this rapid relative sea-level rise are already occurring. In our study area, embankments protecting the landscape were breached in five locations during Cyclone Aila in May 2009 (Fig. 4). The landscape, 1.0-1.5 m below mean high water, remained intertidal for nearly two years until most of the breaches were repaired, temporarily displacing 34,000 people from the area (Mehedi, 2010). Physically, the landscape accumulated 10-80 cm of laminated sediment in the two years it remained tidally inundated (Fig. 5). Our initial conclusion is that these poldered landscapes are highly vulnerable to future inundation because of their low elevation, but tidal energy and abundant sediment supply can also support high potential aggradation rates.

Populations in the region are also strained by a lack of potable water. Regionally, groundwaters are largely saline, but we have also identified that fresh groundwater can provide locally important sources. Overall, though, surface water remains the most commonly used drinking source, but it is being strained by increasing dry-season salinity in river channels and shrimp farming that can salinize soil and surface-water storage. Our investigation of these resources using water chemistry document that: (1) all surface waters are mixtures of saline tidal channel and meteoric water, (2) all groundwaters are mixtures of dilute brine and meteoric water, and (3) salinity contrasts between water sources indicate that surface sediments have low permeability and generally buffer subsurface mixing (Fig. 6).

Social Results – Initial findings from our social-science field research (Fig. 3) indicate that instability at the community level is a function of a lack of (a) multiple livelihoods to secure adequate food and income, (b) access to safe drinking water, (c) intra-community and inter-community cooperation and support, or (d) shared, sustainable uses of land and common-pool resources. Although not yet analyzed, the raw data include evidence of intra-community support and existence of community-based adaptation strategies. Preliminary analysis suggests the need to further study the link between community cohesion and resilience and participation in political decision-making, political transparency, and the accountability of decision-makers to stakeholders.

Our Year 1 findings in the social sciences also suggest that there are numerous factors, measurable at the community level, that can be used to anticipate community stability and instability, and which might also be scaled for use in regional to national studies (once tested). This requires further methodological development, but this preliminary finding is important because it emphasizes that community fate may not be best measured through its vulnerability but through its resilience expressed in having multiple, dynamic, and interconnected adaptive community models.

We also draw important preliminary conclusions that several apparent misconceptions exist regarding climate-change impacts in southwest Bangladesh. The first is that its effects will represent a distinct hazard, very different from the environmental hazards and stresses that the region is currently experiencing. Actually, the effects of climate change will most likely be experienced through their interactions with and perturbations of the same manifold stresses that are already occurring in response to engineering and land-use practices. The second misconception – that these effects will stimulate "mass" migration – can be dispelled by studying current dynamics. Our initial data suggest that the places that will be affected by climate change are already adapted to environment change and thus, insecurity and displacement is likely to be experienced over a longer time scale than the terms "social upheaval" and "mass migration" tend to evoke. This finding does not lessen concern for the people living under these conditions but rather draws attention to the possibility of improving their situation and avoiding negative social, economic and political impacts of environmental change by strengthening the factors that contribute to community resilience.

IMPACT/APPLICATIONS

Our research will ultimately lead us to distinguish those attributes of society and environment that favor stability and resiliency among interconnected communities compared with those that undermine local capacity to thrive within a dynamic physical environment.

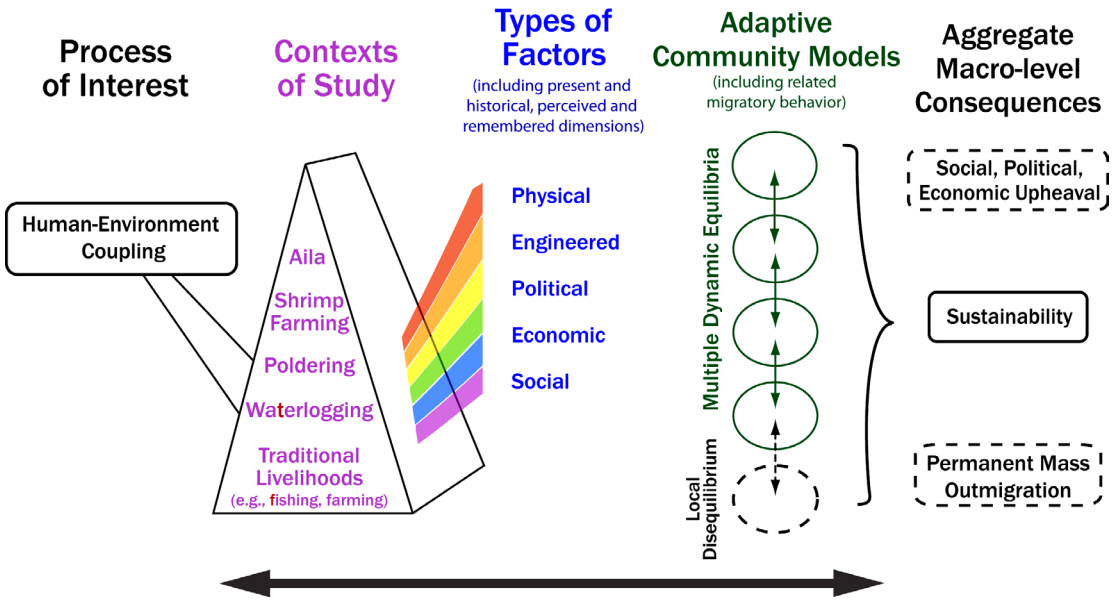

Figure 1. Integrated Social, Environmental, and Engineering (ISEE) model. This model was developed by our team to serve as the primary conceptual framework for all research activities.

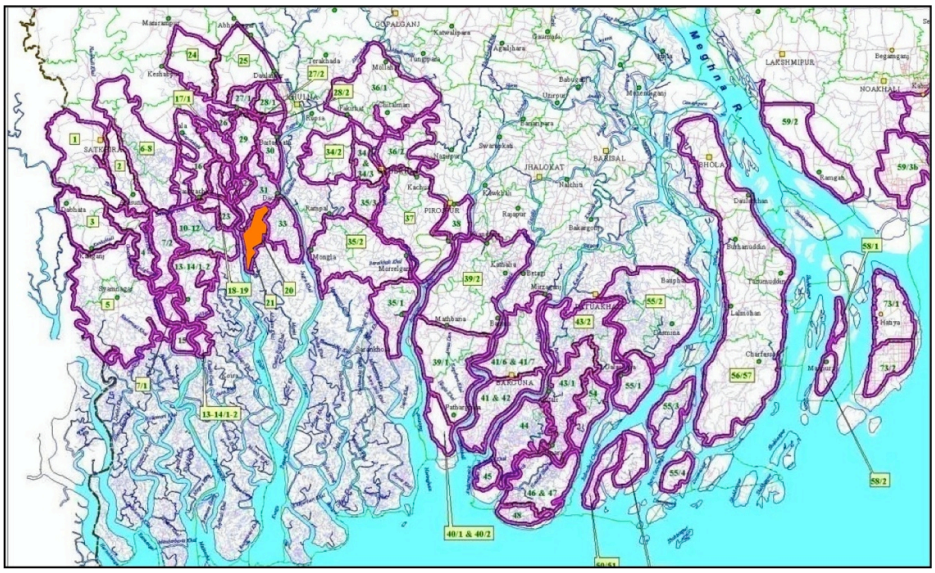

Figure 2. Map of the widespread polder systems in coastal Bangladesh. Polders are lands that have been embanked for protection from flooding. Most embankments were constructed in the 1960s and 1970s as part of the Coastal Embankment Project, which was aimed at increasing arable land for paddy cultivation and famine relief. The Year 1 project site is shown in orange.

Figure 3. Field photos from the study area. (upper left) Photo of an embankment at high tide, highlighting relative elevation difference (~1.5 m) between high water and the poldered landscape; (upper right) The 'hanging village', a fishing community living along the embankments; (lower left) PI Brooke Ackerly interacting with families in the 'hanging village'; (lower right) Group of women following an interview for seasonal livelihood mapping via participatory rapid appraisal.

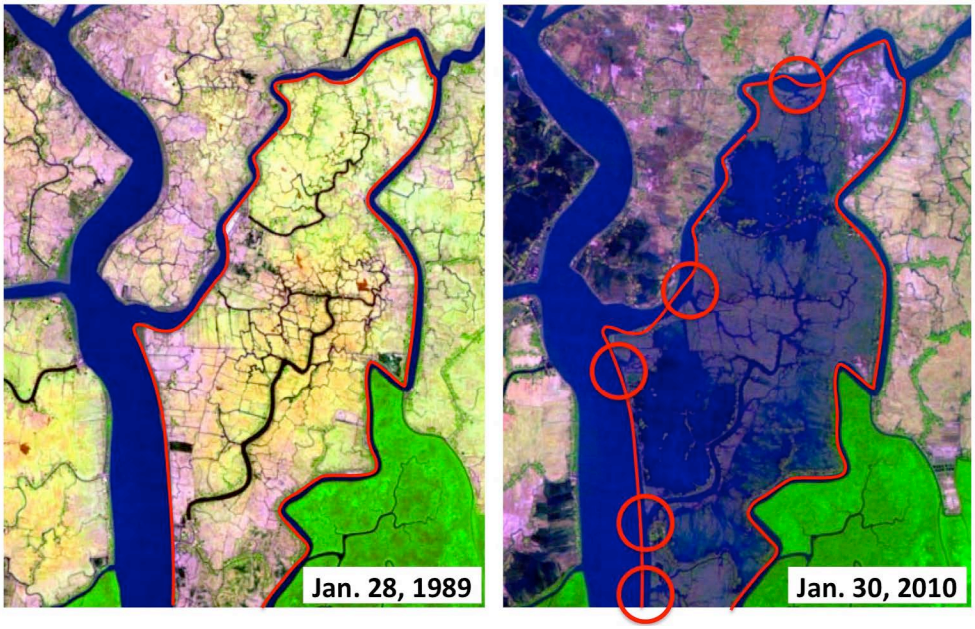

Figure 4. Dry-season Landsat images of the focus study area in 1989 and 2010. 2010 image taken 8 months after Cyclone Aila, showing most of the landscape wet or inundated by tidal waters (image taken near low tide). Red lines show 1989 bank positions, with red circles denoting the location of five major breaches caused by Cyclone Aila, all occurring at locations of historical channel-bank migration.

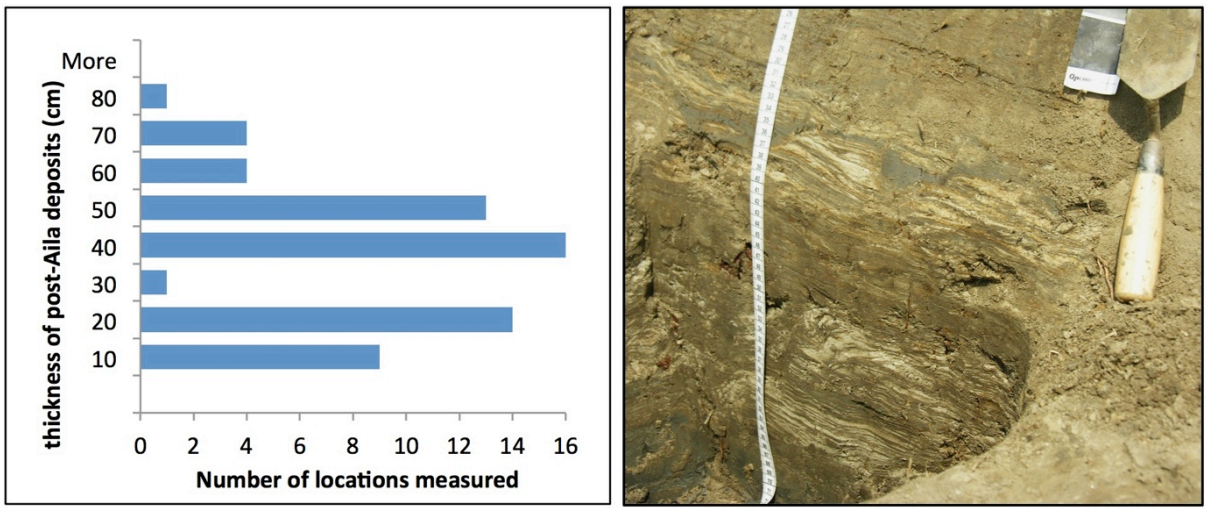

Figure 5. Distribution plot of post-Aila tidal sediment deposition in the study area (left) and photo of the lower half of a 72-cm thick, finely laminated post-Aila sediment deposit (right). Nearly two years of daily tidal inundation led to the deposition of 10-80 cm of tidally laminated sediments in the polder. These deposits reflect both the hardship endured through this time period, continuing today with reduced fertility soils, but also the resilience of the natural landscape to transport and deposit large volumes of sediment in response to relative sea-level changes.

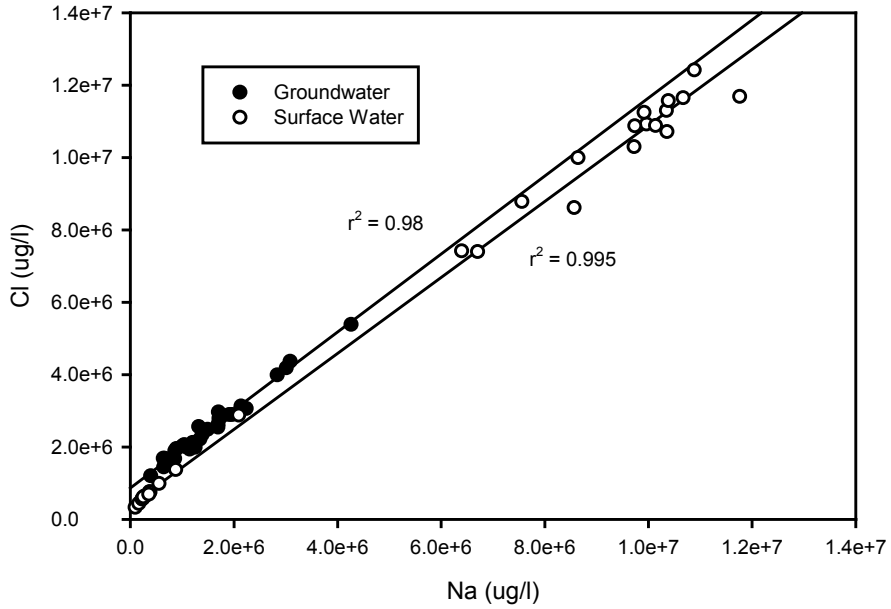

Figure 6. Plot of conservative Cl^- and Na^+ ion concentrations in groundwater and surfaces water samples from the study area. These results show the clear mixing trends between different end-member water sources. Surface-water samples reveal both fresh and saline sources that primarily originate with the the storage of wet- and dry-season tidal channel waters, respectively. The groundwater samples are mostly too saline to be potable, but they are considerably fresher than dry-season surface waters and suggest that groundwaters may represent a largely fresh source mixed with small amounts of higher salinity water.

RELATED PROJECTS

Several PIs from the physical-science team of the ONR MURI project are also collaborating on a National Science Foundation study investigating coupled fluvial-tectonic-basin interactions in the Bengal Basin and Ganges-Brahmaputra River delta. This project is led by ONR co-PI Michael Steckler at Columbia University, and also includes other ONR co-PIs Steven Goodbred (Vanderbilt) and Leonardo Seeber (Columbia). The project is funded through NSF International Program's Partnerships for International Research and Education (PIRE). The project title is "Life on a tectonically active delta: Convergence of earth science and geohazard research in Bangladesh with education and capacity building". More information can be found at the project homepage http://www.banglapire.org/. To date the most important links between the studies are expanded capacity for monitoring and understanding tectonic deformation of the basin and its impacts on subsidence, sedimentation, and river behavior.